FORM OF LARGE SCALE HYBRIDS

BEING DEFINED BY A VISION 21 PROGRAM

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PRESENTATION OUTLINE

- HOW THE LARGE SCALE HYBRIDS TOOK SHAPE
  - VISION 21 PROGRAM BACKGROUND
  - WHY HYBRIDS CHOSEN
    - SUB-SYSTEM SELECTION
    - SCREENING ANALYSIS

- SHAPE OF LARGE SCALE HYBRIDS FURTHER DEFINED
  - A DETAILED ANALYSIS TO DEVELOP
    - SYSTEM CONFIGURATIONS
    - OVERAL PERFORMANCE ESTIMATES

- DEVELOPMENT NEEDS TO MAKE LARGE SCALE HYBRIDS INTO REALITY
  - FUEL CELLS
  - GAS TURBINES

VISION 21 PROGRAM ORIGINAL GOALS

- **PRODUCE ELECTRICITY & TRANSPORTATION FUELS AT COMPETITIVE COSTS**
- **MINIMIZE ENVIRONMENTAL IMPACTS ASSOCIATED WITH FOSSIL FUEL USEAGE**
- **ATTAIN HIGH EFFICIENCY**
  - **NATURAL GAS: 75% (LHV)**
  - **COAL: 60% (HHV) (W/O CO_2 CAPTURE/SEQUESTRATION & CO-PRODUCTS)**
  - **COAL WITH CO-PRODUCTION: ELECTRIC POWER (CORRECTED FOR EFFICIENCY) + LHV IN CO-PRODUCT $\geq$ 75%**

VISION 21 PROGRAM OBJECTIVE

- **IDENTIFY NATURAL GAS & COAL BASED CYCLE CONFIGURATIONS THAT MEET V21 GOALS FOR**
  - **ELECTRIC POWER ONLY**
  - **ELECTRIC POWER WITH CO_2 CAPTURE FOR SEQUESTRATION**
  - **ELECTRIC POWER WITH CLEAN FUEL CO-PRODUCTION**

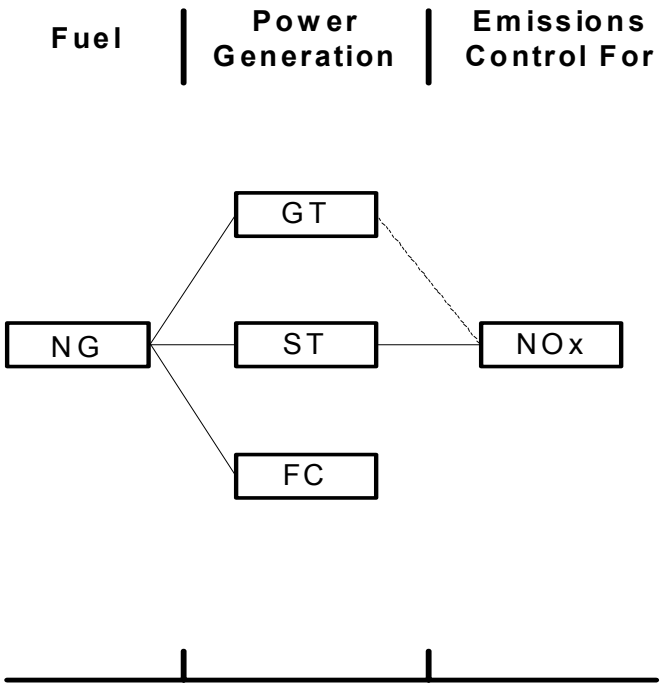
APPROACH

- **SUB-SYSTEM SELECTION – SELECT FUEL PROCESSING, POWER GENERATION, & EMISSION CONTROL TECHNOLOGY SCENARIOS WITH POTENTIAL TO ACHIEVE V21 GOALS**

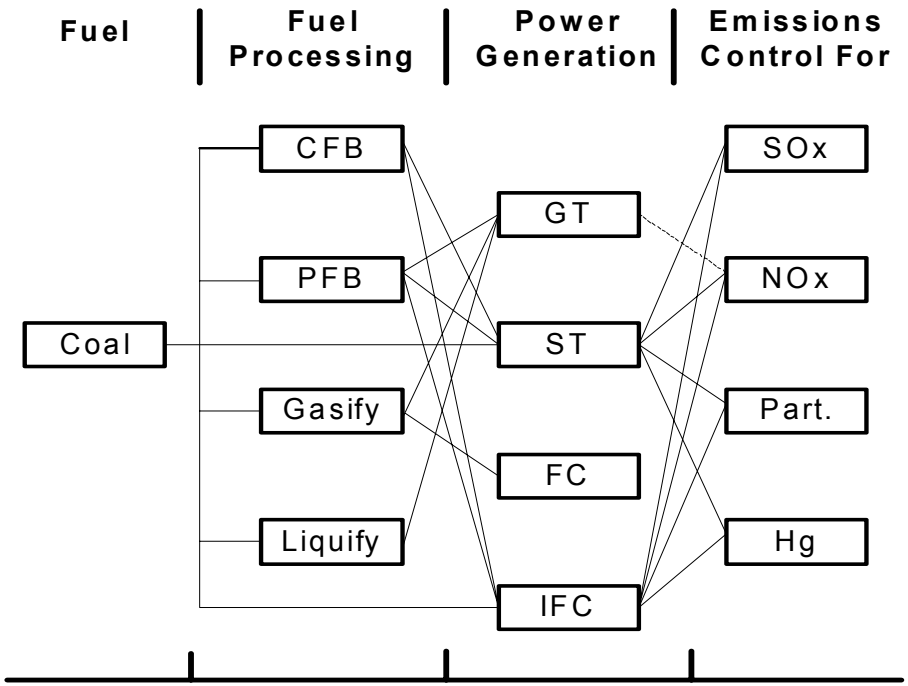
- **SCREENING ANALYSIS – ANALYZE/OPTIMIZE SELECTED TECHNOLOGY SCENARIOS TO SELECT CYCLE CONFIGURATIONS**
  - **START WITH BASIC DESIGN WITH RELATIVELY NEAR TERM TECHNOLOGY**
  - **IF V21 TARGETS NOT REALIZED, INCORPORATE MORE ADVANCED DESIGNS**

- **DETAILED ANALYSIS – ANALYZE SELECTED PROMISING CYCLES TO DEVELOP DETAILED PERFORMANCE & ROM COST ESTIMATES**

SUB-SYSTEM SELECTION



(a) Natural Gas Fueled

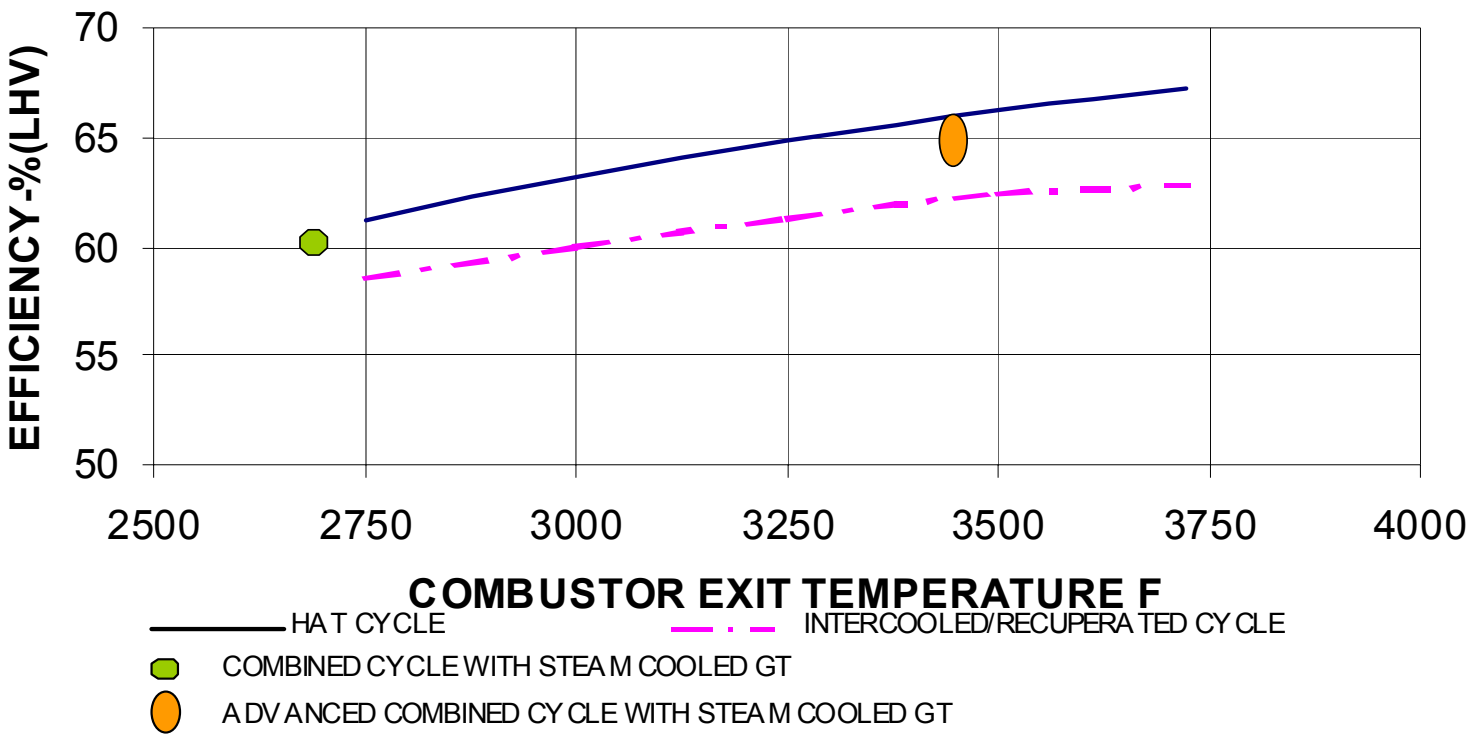


(b) Coal Fueled

NG-Natural Gas
CFB-Circulating Fluided
FC-Fuel Cell
GT-Gas Turbine

PFB-Pressurized Fluid Bed
IFC-Indirectly Fired Cycle
ST-Steam Turbine

GAS TURBINE W/O FUEL CELL NOT SUFFICIENT



SUB-SYSTEM SELECTION

- GAS TURBINES + FUEL CELLS REQUIRED TO ATTAIN V21 EFFICIENCY GOALS
- COAL CONVERSION TO CLEAN GAS REQUIRED TO UTILIZE GAS TURBINES/FUEL CELLS
- REQUIRES COAL GASIFICATION

SCREENING ANALYSIS
NATURAL GAS CASES

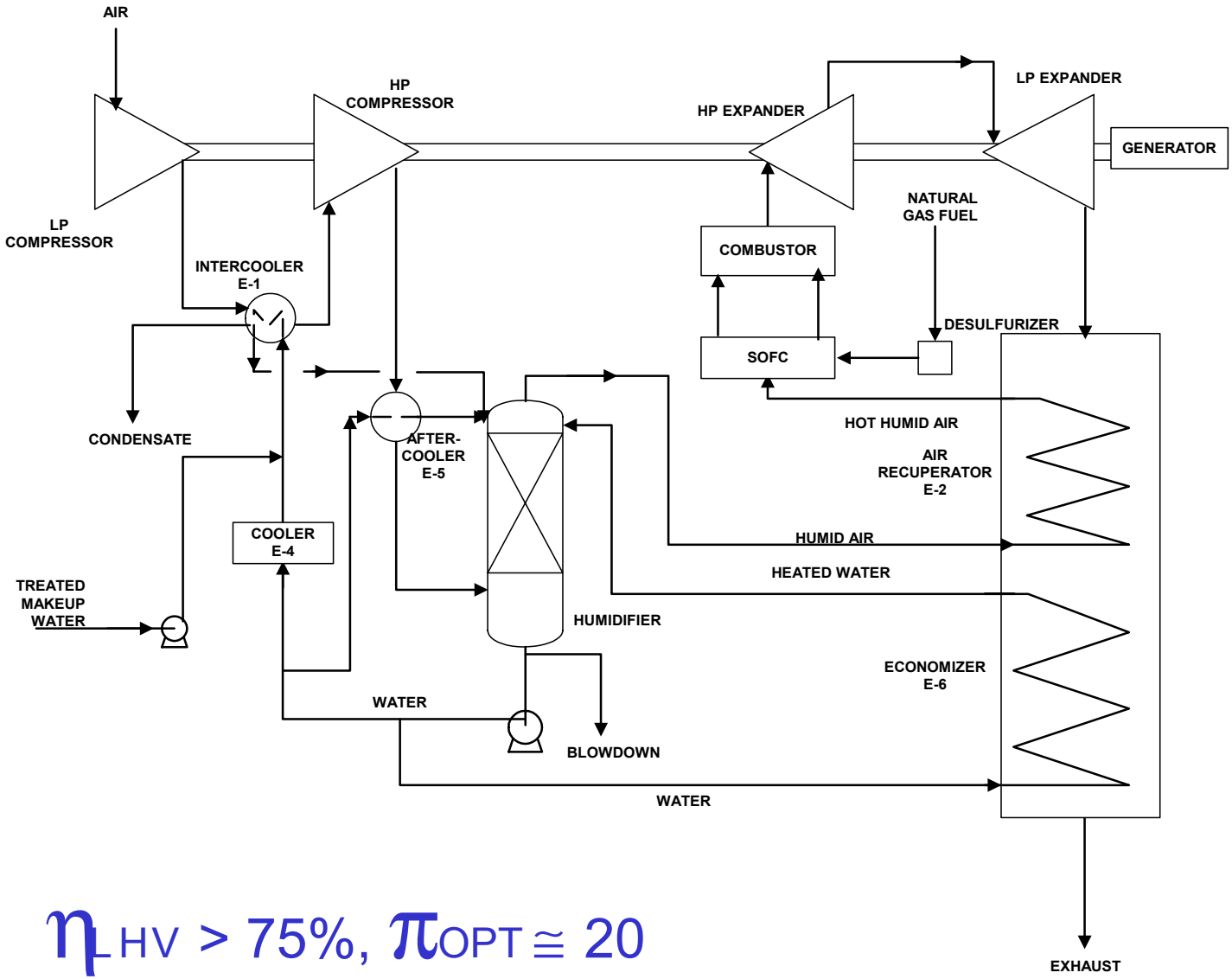
THERMAL EFFICIENCY

- HIGH PRESSURE SOFC / IC GT HYBRID
- HIGH PRESSURE SOFC / HAT HYBRID
- ATMOSPHERIC PRESSURE MCFC / CHEMICALLY RECUPERATED GT (WITH HITAF) HYBRID

CO_2 RECOVERY

- O_2 BREATHING HIGH PRESSURE SOFC / HAT HYBRID WITH TEMP MODERATED BY CO_2 RECYCLE
- ADVANCED RANKINE CYCLE (GT) WITH CES COMBUSTOR & HIGH TEMP H_2 SEPARATING MEMBRANE

SOFC / HAT



ADVANCED GAS TURBINE TECHNOLOGY – HAT REQUIRED

ADVANCED FUEL CELL TECHNOLOGY – HIGH PRESSURE & HIGH CURRENT DENSITY REQUIRED

$\eta_{LHV} > 75\%, \pi_{OPT} \cong 20$

RESULTS
NATURAL GAS CASES

	HP SOFC + IC GT HYBRID	HP SOFC + HAT HYBRID	ATM P MCFC + IC GT HYBRID	O_2 BREATHING HP SOFC + HAT HYBRID	ADV RANKINE (H_2/O_2 COMBUSTION)
%OF TOTAL POWER BY FUEL CELL	72	68	74	68	-
%OF TOTAL POWER BY GAS TURBINE	28	32	26	32	100
THERMAL EFFICIENCY, % LHV	>75	>75	70	>60	52
SPECIFIC POWER, KW/LB/S	985	1000	830	800	-

SCREENING ANALYSIS
COAL BASED CASES

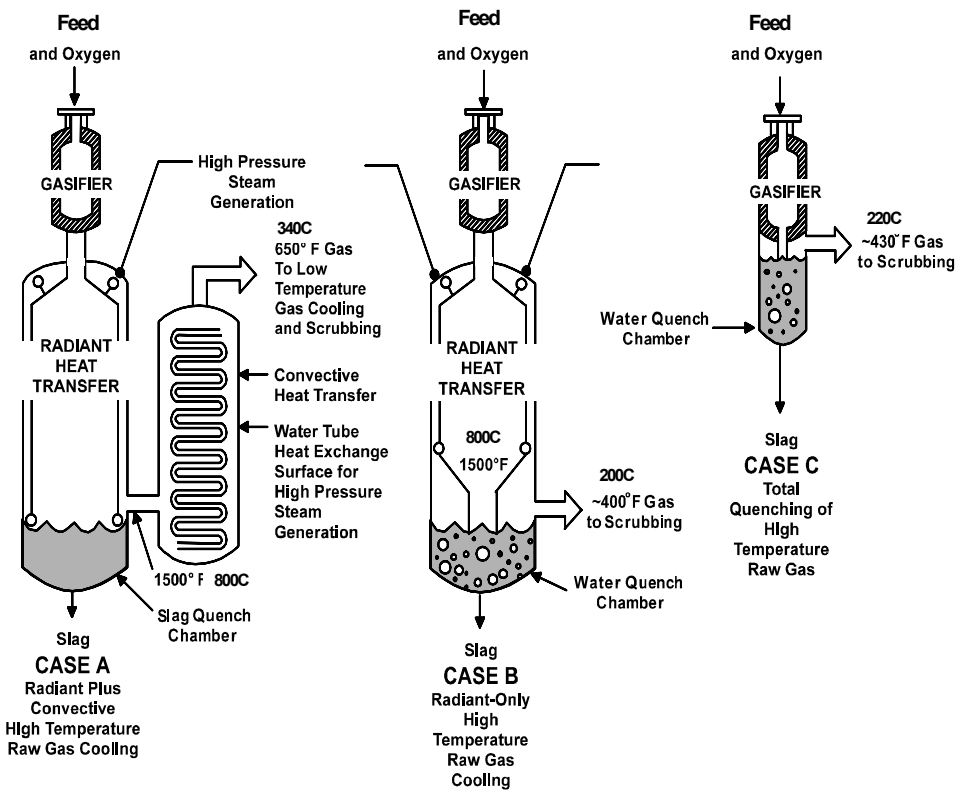
THERMAL EFFICIENCY

- SHELL TYPE GASIF / HT CLEANUP - SOFC HYBRID
- TEXACO TYPE GASIF – SOFC / HAT HYBRID
- F-W PARTIAL GASIF - SOFC / HITAF GT HYBRID

CO_2 RECOVERY

- SHELL TYPE GASIF / HT CLEANUP - O_2 BREATHING H P SOFC / HAT HYBRID WITH TEMP MODERATED BY CO_2 RECYCLE
- SHELL TYPE GASIF / HT CLEANUP / SHIFT / HT H_2 MEMBRANE SEPARATION - ADVANCED RANKINE CYCLE (GT) - CES COMBUSTOR

HT ENTRAINED BED SLURRY FED (TEXACO) GASIFIER



- GAS LEAVES AT HIGH TEMP (>2200F OR 1200C)

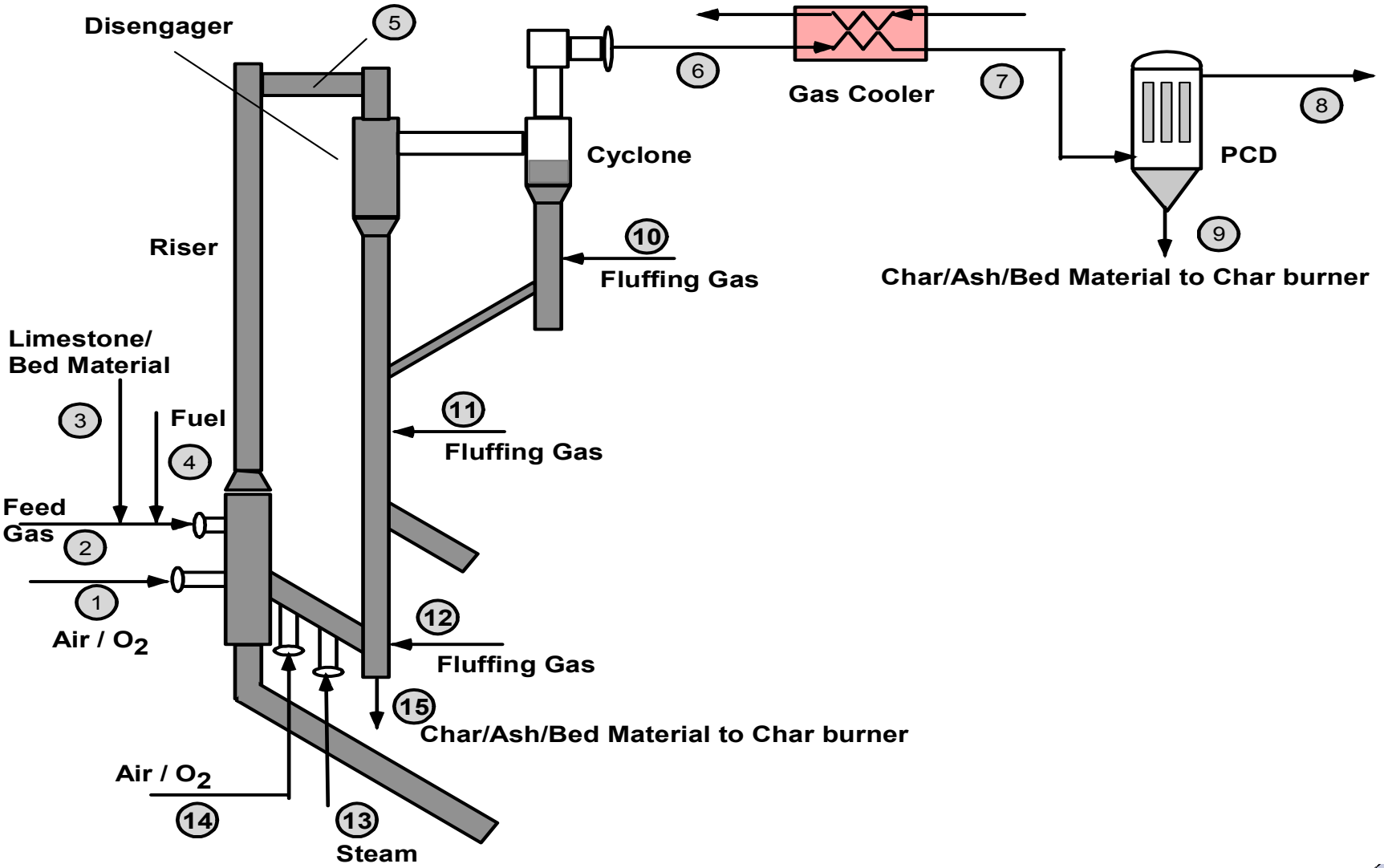
  - LESSER COAL BOUND ENERGY CONSERVED AS CHEMICAL ENERGY OF FUEL GAS
- GASIFIER CAN BE OPERATED AT VERY HIGH PRESSURES (80 BAR)
- CASE C ESPECIALLY SUITABLE FOR SOUR SHIFT

RESULTS
COAL BASED CASES

- CONVENTIONAL HT GASIFICATION
  - DIFFICULT TO MEET V21 EFFICIENCY GOAL
    - EVEN WITH HYBRIDS
    - PLUS HT GAS COOLING TECHNOLOGIES

- NEED LOWER TEMP GASIFICATION
  - V21 EFFICIENCY GOAL MET
    - MORE OF THE COAL BOUND ENERGY CONSERVED AS CHEMICAL ENERGY IN FUEL GAS
    - EXAMPLE: ADVANCED TRANSPORT REACTOR (ATR)

MODERATE TEMP GASIFICATION THE ATR



DETAILED ANALYSIS

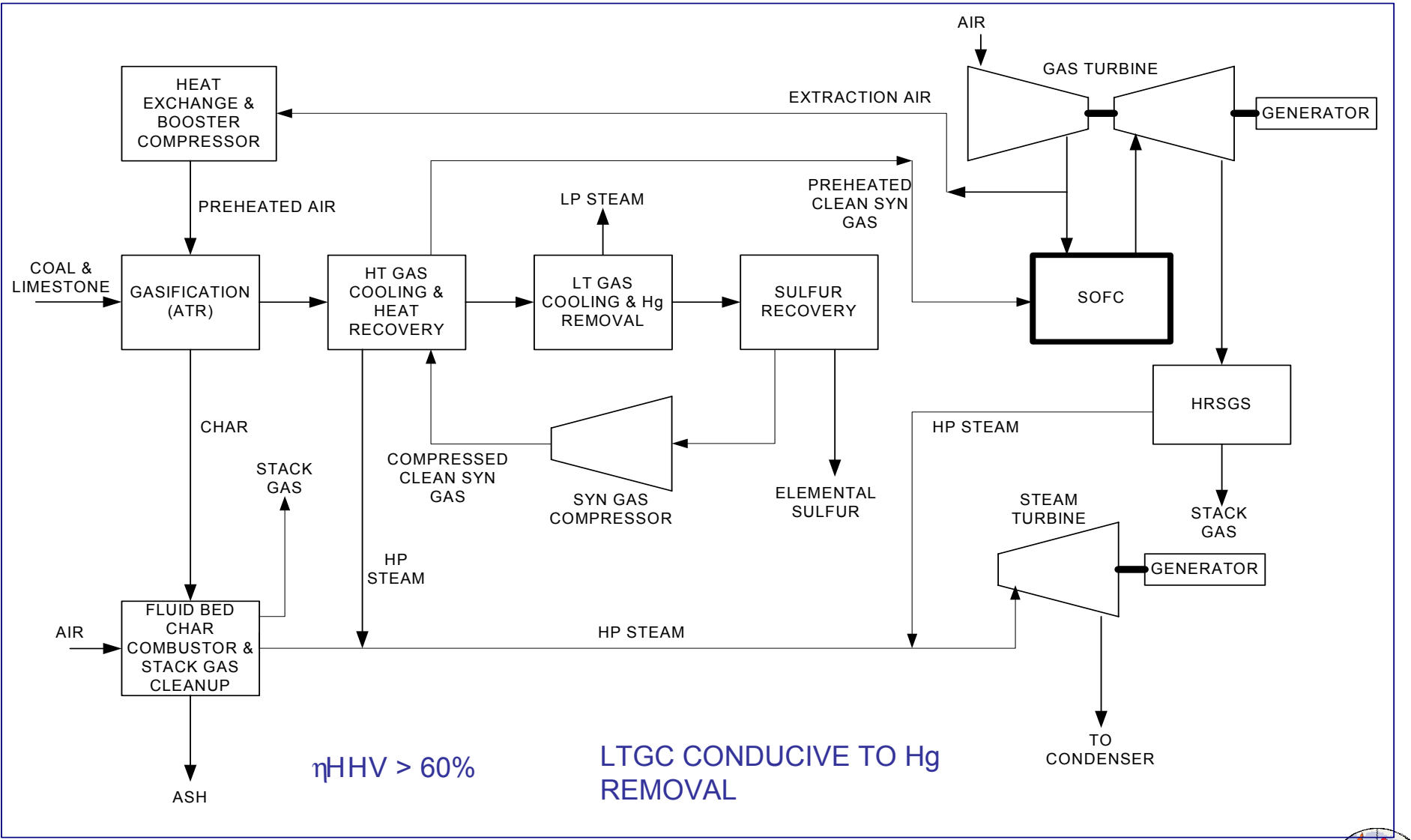
NATURAL GAS

- HIGH PRESSURE SOFC / HAT HYBRID – AN EFFICIENCY CASE

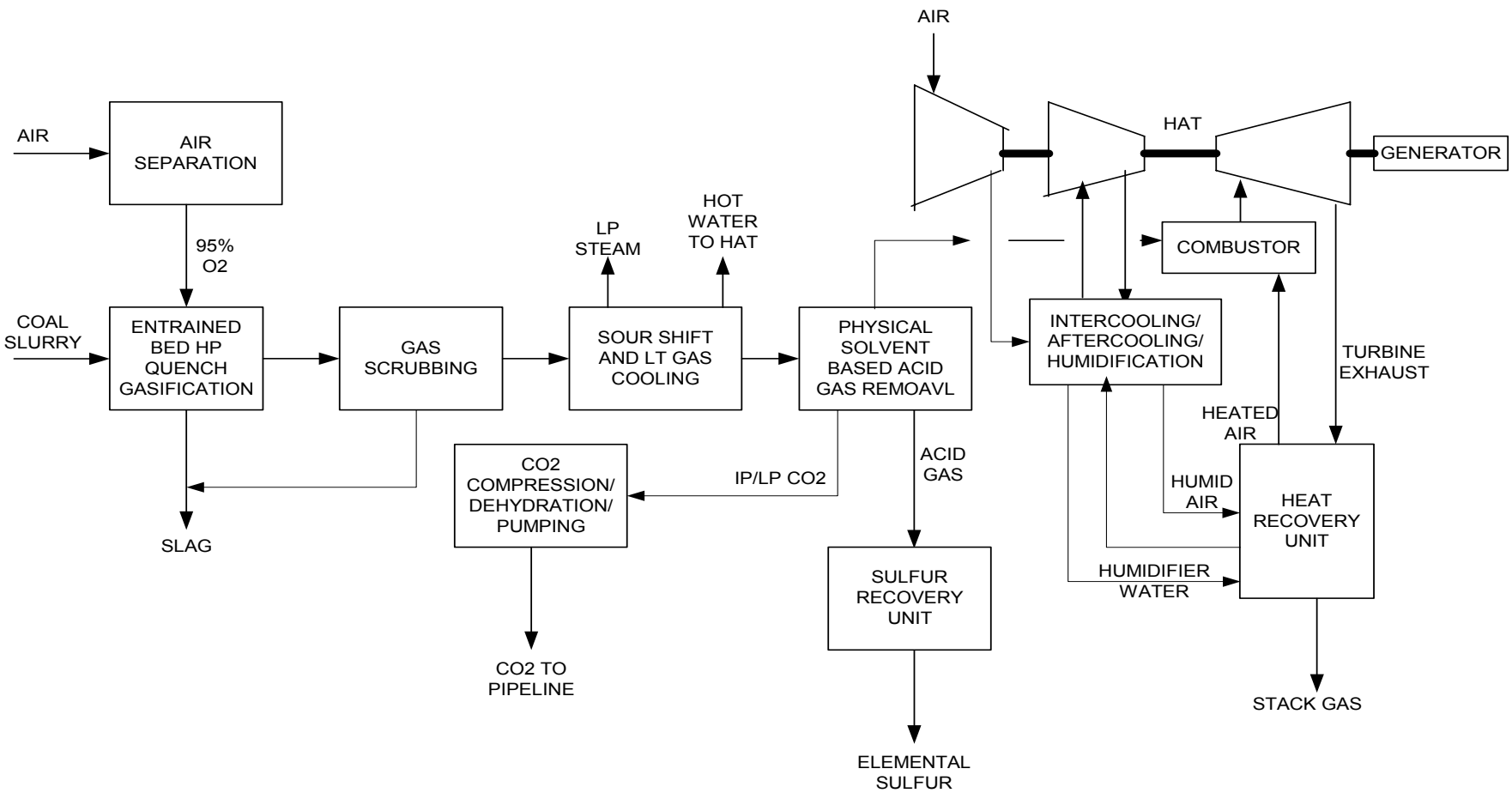
COAL

- ATR BASED SOFC HYBRID – AN EFFICIENCY CASE
- CO_2 CAPTURE CASES
  - V21 TECHNOLOGY
  - CURRENT TECHNOLOGY
- H_2 COPRODUCTION CASE

ATR BASED SOFC HYBRID

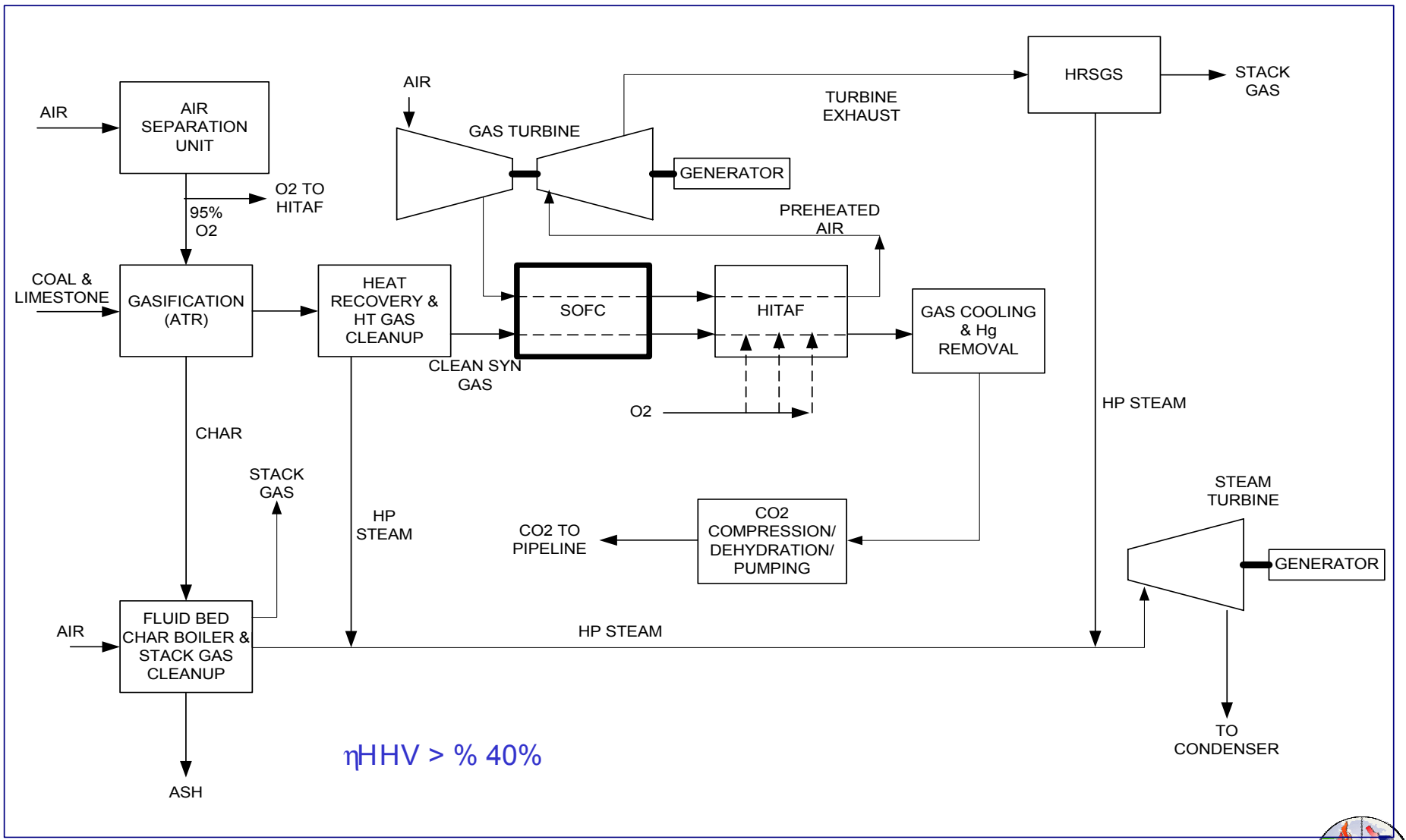


CO2 CAPTURE WITH NEAR TERM TECHNOLOGY

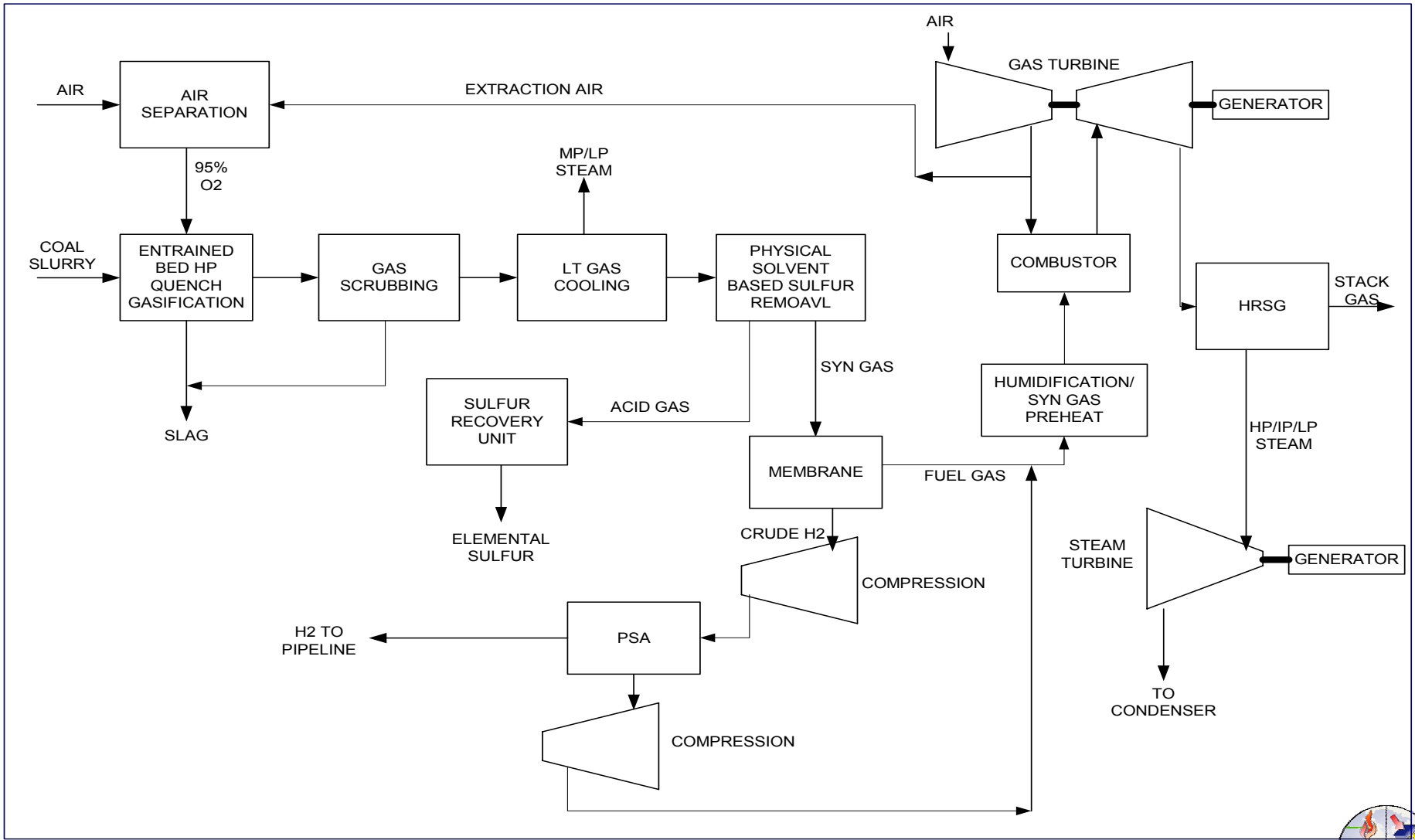


ηHHV > % 33%

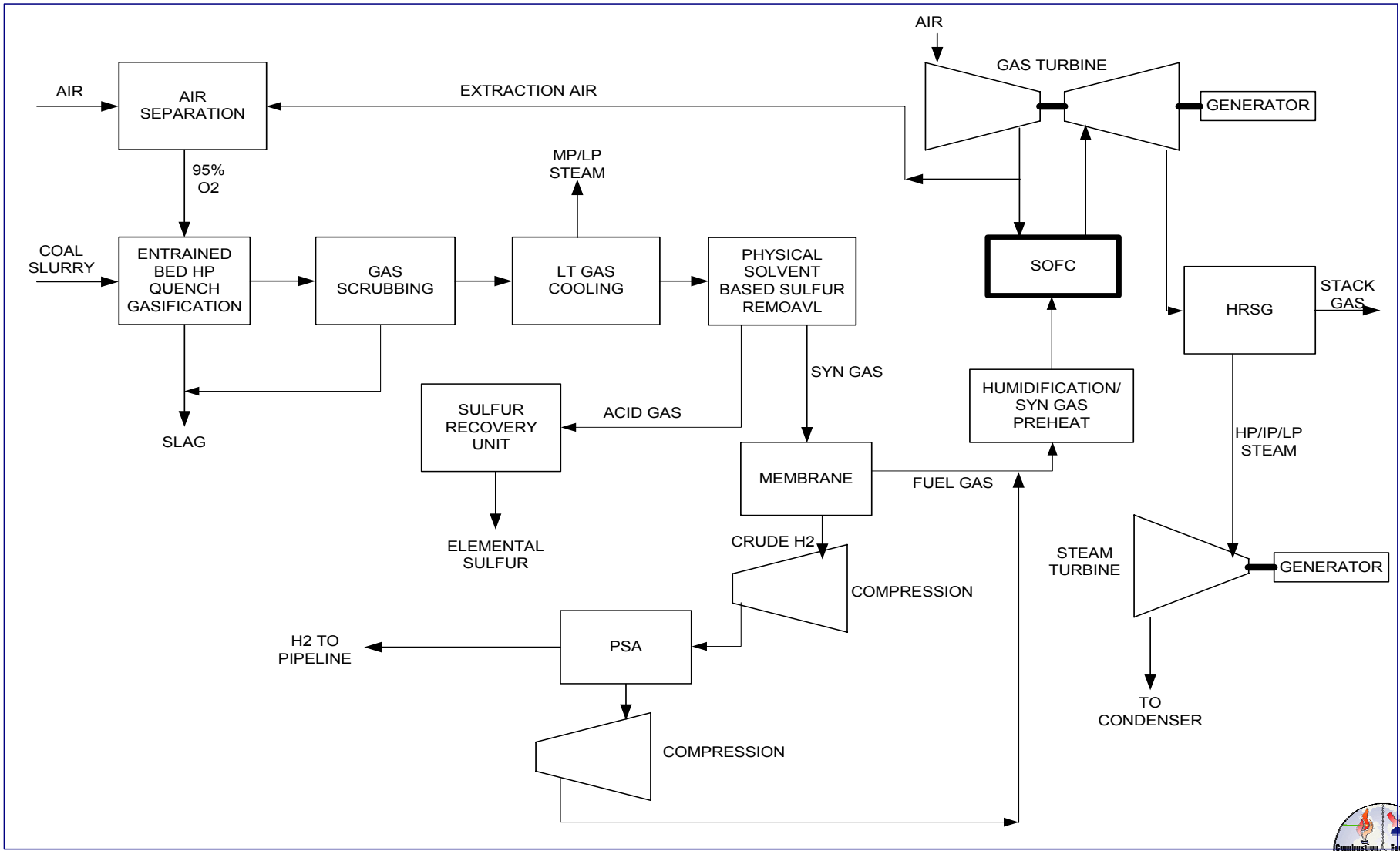
CO2 CAPTURE WITH VISION 21 TECHNOLOGY



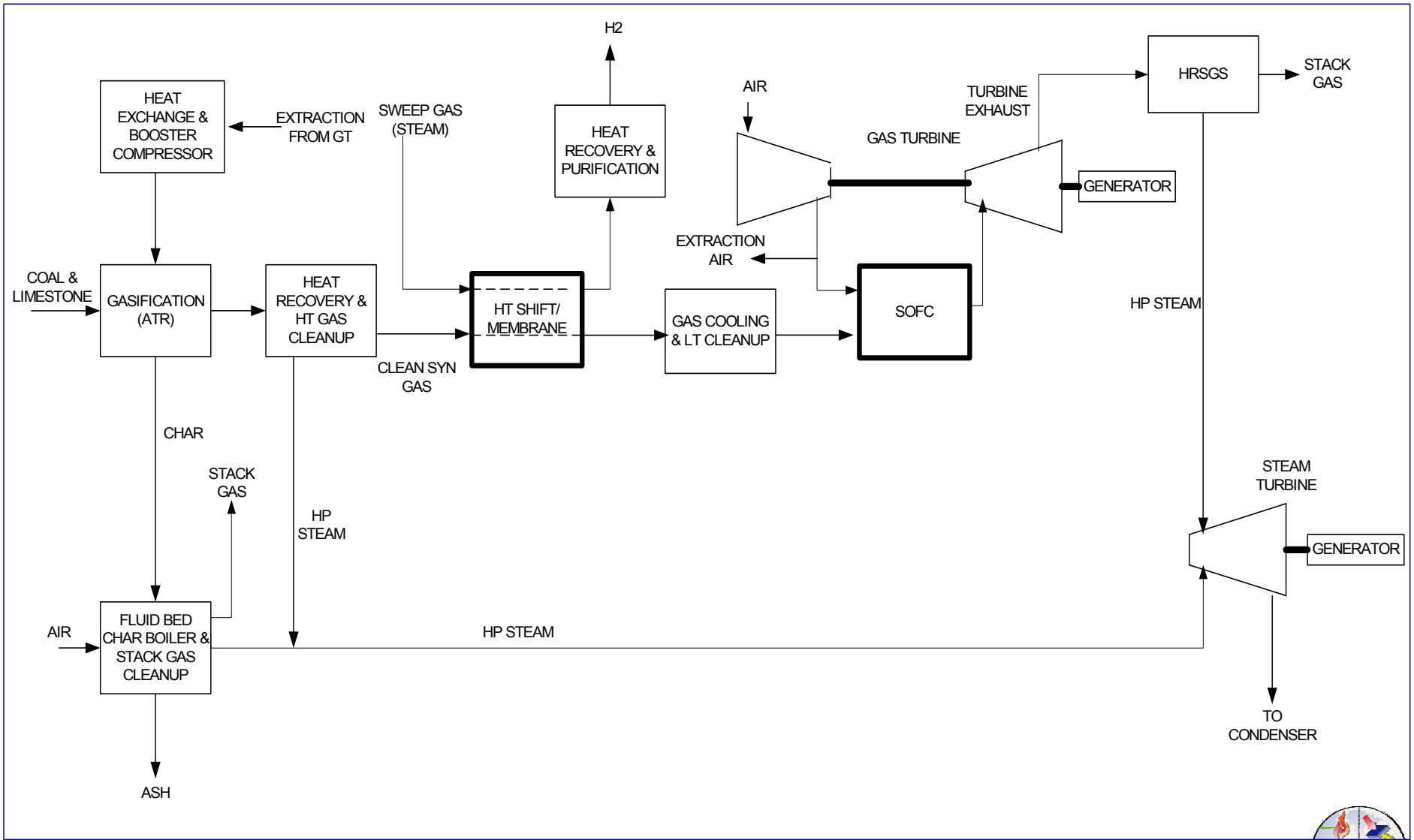
CURRENT TECHNOLOGY "FUTURE GEN TYPE PLANT" COPRODUCTION OF H2



HYBRID "FUTURE GEN TYPE PLANT" COPRODUCTION OF H2



HYBRID "FUTURE GEN TYPE PLANT" COPRODUCTION OF H2 WITH HT MEMBRANE



TECHNOLOGY DEVELOPMENT NEEDS (1)

FUEL CELLS

- **HIGH PRESSURE SOFCs**
  - **PRESSURE OF 20 BAR >> DEMONSTRATED**
- **HIGHER CURRENT DENSITY MATERIALS (W/O EXTENSIVE USE OF EXOTIC MATERIALS)**
  - **TO LIMIT PHYSICAL SIZE OF 200 MW FUEL CELLS**
  - **TO LIMIT STACK MODULES & MINIMIZE HT PIPING/MANIFOLDING**
  - **FUEL CELL COST WILL BE REDUCED**

TECHNOLOGY DEVELOPMENT NEEDS (2)

FUEL CELL HEAT MANAGEMENT

- NEAR STOICHMETRIC AIR/FUEL RATIO REQUIRED IN FUEL CELL FOR HIGH EFFICIENCY IF GT DEVELOPMENT LIMITED TO NONREHEAT
  - MANAGEMENT OF HEAT GENERATED WITHIN CELLS CHALLENGING
  - INTERNAL REFORMING REQUIRED
  - WATER VAPOR ADDITION TO FUEL/AIR (HAT) ASSISTS AS HEAT SINK
  - & INCREASES MOTIVE FLUID IN TURBINE (WATER INTRODUCED EFFICIENTLY, HUMIDIFIER RECOVERS LT HEAT)
  - BUT DECREASES PARTIAL PRESSURE OF REACTANTS, INCREASES CELL POLARIZATIONS
  - BALANCE BETWEEN TWO REQUIRED
  - HP CATALYTIC ANODE EXHAUST GAS COMBUSTORS

TECHNOLOGY DEVELOPMENT NEEDS (3)

GAS TURBINES

- **LARGE (~150 MW) INTERCOOLED-RECUPERATIVE GTs REQUIRED**

- **LARGE GTs WITH COMBUSTORS ACCEPTING HOT & DEPELTED FUEL & AIR REQUIRED (WHEN GT COMBUSTOR USED)**